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Exploring the Scientific Facts

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Within-Farm Variability in Soil Fertility Management in Smallholder Farms of Kirege Location, Central Highlands of Kenya

J.M. Muthamia, D.N. Mugendi, and J.B. Kung'u

Abstract Smallholder farms in Central Highlands of Kenya exhibit a high degree of heterogeneity, determined by a complex set of socio-economic and biophysical factors. The farms consist of multiple plots managed differently in terms of allocation of crops, nutrient inputs and labour resources, making within-farm soil fertility gradients caused by management strategies a common feature. In most cases, nutrient inputs are preferentially allocated to home fields, whilst outfields are neglected. A monitoring study involving nutrient inputs, flows and balances was conducted in Kirege location, where nine case study farms were used. The study was to compare the intensity of soil fertility management between home fields, mid-fields and outfields. It also compared soil fertility management practices between three different resources endowment classes to reveal important differences in patterns of fertility management. The farms were visited to record movement of nutrient-containing materials using a monitoring protocol covering household, crops, livestock, soil and socio-economic aspects of the farm. Data obtained was analyzed using IMPACT program version 2.0 to obtain total nutrient inputs and balances at field and farm levels and statistical analysis done using GenStat Discovery edition 2. Results revealed that mean N inputs over all resource endowment classes decreased with distance to the homestead (from 94 to 22.9 kg ha^{-1}), as did P (from 54.6 to 15.6 kg ha^{-1}) and K (from 193 to 34 kg ha^{-1}). Due to this heterogeneity in smallholder farms, there is a need for a more targeted approach to soil fertility intervention that differentiates between farm fields, agro-ecological zone and resource endowment status.

Keywords Heterogeneity · Home fields · Nutrient inputs · Outfields · Soil fertility gradient

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Introduction

Decline in soil fertility has been described as the fundamental constraint to productivity of smallholder farms in sub-Saharan Africa (Sanchez et al., 1997). Most farmers cultivate crops continuously on the same plots with little additions of nutrient resources, which has led to severe depletion of soil fertility. Traditionally, smallholder farmers relied on long fallow periods under shifting cultivation to replenish soil fertility. Shifting cultivation, however, has disappeared as increasing population density and pressures on land use led to intensive, sedentary agriculture on small-scale landholdings and expansion of agriculture into marginal areas. This intensification of agriculture in small landholdings has typically not been accompanied by sufficient inputs of nutrients through biological nitrogen fixation, organic materials and mineral fertilizers to match the outputs of nutrients through harvested products and losses.

The processes of nutrient depletion and soil degradation, however, are spatially heterogeneous, as determined by the underlying parent material and geomorphology and by (current and historical) management (Smaling et al., 1997). Causes of variability in soil fertility status at different scales (i.e. region, village, farm and field) are both biophysical and socio-economic.

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Variability at regional scale is determined by climate and dominant soil types, presence of and access to factor and product markets and historical, socio-cultural and ethnic aspects defining land use. The variability between different farm types (resource endowment groups) is associated with differences in soil fertility management between poor and wealthy households (Crowley and Carter, 2000). For instance, Murage et al. (2000) in a study in central Kenya reported differences in chemical and biological soil properties of productive and non-productive fields within a farm. Since clay and sand contents did not vary between soil categories in their study, they suggested that these differences in chemical and biological soil properties are not inherent but result from past soil management. Their findings reveal that farmers are more likely to allocate their limited organic resources and fertilizers to higher value crops in more productive areas of the farm than to attempt amelioration in fertility-depleted fields.

Here, we describe a monitoring study that was undertaken to understand within-farm variability in soil fertility management in smallholder farms of Kirege location, Central Highlands of Kenya. This was seen as a necessary step in identifying spatial–temporal niches for targeting of soil fertility management strategies and technologies. The objectives were (i) to construct farm typologies that reflect potential access of households to resources for managing their soils, (ii) to determine the magnitude of the nutrient flows and balances at farm scale, (iii) to compare soil nutrient inputs between home fields and outfields and (iv) to assess the influence of resource endowment on soil fertility management and nutrient balances.

Materials and Methods

The Study Site

The study was conducted in Kirege location, Chuka Division, in Meru South District. This area is a predominantly maize-growing zone. It is in the upper midland zones two and three (UM2–UM3) (Jaetzold and Schimdt, 1983). The area lies on the eastern slopes of Mt. Kenya at an altitude of approximately 1,500 m above sea level within an annual mean temperature of 20°C. It has an annual rainfall ranging from 1,200 to 1,400 mm and is bimodal, falling in two distinct seasons. The long rains (LR) occur from March to June and the short rains (SR) from October to December. The soils are deep, well-drained, weathered humic nitisols (commonly called red Kikuyu loams) with moderate to high inherent fertility (Jaetzold and Schimdt, 1983).

The area is highly populated with a population density of about 700 persons per km^2 (Mutegi, 2004). Land is owned individually under freehold system of land tenure. Smallholder mixed farming is the most predominant farming system in the area. A wide variety of cropping systems as well as species and breeds of crops and livestock are found within individual farm holdings. Coffee (*Coffea arabica*) and tea (*Camellia sinensis*) are the major cash crops, while maize (*Zea mays*) and beans (*Phaseolus vulgaris*) are the main food crops in the area. Other food crops include potatoes, cassava, bananas, sweet potatoes, and various fruits and vegetables. Cattle, sheep, goats and poultry are the most common livestock species in the area.

Development of Farm Topology and Selection of Case Study Farms

A community meeting was organized and focus group discussions conducted to identify farmer criteria to be used as a basis for grouping themselves into different wealth classes. Farmer-identified indicators of wealth status were ranked, and this formed a basis for grouping farmers into different wealth status. A rapid survey was conducted using a sample of 50 households randomly selected out of the list of households in Kirege obtained from the local chief's office to characterize and classify the farms into three different groups (rich, medium and poor). During the survey and farm walks, it was observed that there were no significant differences in the biophysical characteristics (climate and soil type) of the farms in the village. Having confirmed the resource endowments of the farms through farm walks, nine case study farms were randomly selected for detailed resource flow mapping. There were three from each of the three wealth categories (referred to as resource groups or farm types) that had been identified.

Development of Field Topologies

The farms selected for detailed study above were visited to sensitize the farmers on the nutrient monitoring exercise. During the visit, the researcher together with the farmers drew sketch farm maps to indicate location of farm plots under various activities/enterprises. An inventory was conducted to identify the important features of the farm to be studied, such as fields, crops, animals, compost pits, household composition, farm size, farm implements and facilities. Area of farm plots, their coordinates and distance from the homestead were obtained by use of a Global Positioning Unit (GPS). The fields within each farm visited were also classified using a field typology that described resource allocation patterns and internal (within farm) nutrient flows that affect soil fertility (Mapfumo and Giller, 2001). Land use and distance from the homestead were the main criteria used to classify field types (home fields, mid-fields and outfields) (Tittonell, 2003).

Resource Flow Mapping and Calculation of Partial Nutrient Balances

The farms were first visited in August 2006 and farmers were asked to draw schematic maps and indicate all production units and the flows of nutrients to and from the units identified. Additionally, the type and number of crops grown, use or destination of the outputs, type and amount of inputs used, timing of crop and soil management activities and sequential order within the farm, sources of labour, off-farm income, average yields and general crop and livestock husbandry practices adopted were recorded using datasheets of IMPACT. A seasonal time frame was used, considering the long rains (March to August) of 2006 and farmers were asked recall questions relating to the above-mentioned aspects of farm management. In the second season (2006/2007 short rains), a monitoring approach was adopted where farms were regularly visited from September when farmers were preparing their land to March when the crops were harvested to monitor the flow of nutrients in the farms. During the monthly visits, farmers were interviewed to provide information on crop and livestock husbandry practices between then and the previous visit.

During resource flow mapping, farmers indicated quantities of inputs and outputs to the different production units/fields in local units, such as *tins* (±2 kg of grains), *debes* (±16 kg of grains), bags (±90 kg of grains), bunches of bananas (±40 kg) and head loads (±40 kg of Napier grass or maize stover), and these were converted into SI units. Many of the values in kilogram given to local units were taken from previous work in the region and farmers' own experiences with the products. Parameters such as dry matter and nutrient contents (N, P and K) of materials that were most frequently used and therefore core determinants of nutrient movements were taken from literature (Rotich et al., 1999, Palm et al., 2001, TSBF, 2001) The main groups of these products included crop products, crop residues, manure and compost. This data was entered into IMPACT version 2.0 model for analysis.

Data Analysis and Presentation

Data obtained during the study was analyzed by use of IMPACT program version 2.0. Nutrient inputs and balances were calculated both for the farms as units and for field(s), separating nutrient sources into off-farm and on-farm sources. Data obtained was subjected to ANOVA using GenStat Discovery edition program with farm types and field types used as factors and nutrient inputs and balances as variates. Comparisons were made between 'farm types' and 'field types' for both nutrient inputs and balances and their means separated using least square difference (LSD) at 5% level of significance.

Results and Discussion

General Description of Households in Kirege

In order to provide a contextual background to farmers' soil fertility management practices and to explain their choice of strategy, this section examines the empirical results of a household survey on socio-economic characteristics (Table 1).

About 79% of the sampled households were male headed as compared to 21% female-headed households. Seventy-two percent of the household heads were married with spouse present, 13% married with spouse absent, 11% widows or widowers and 4% single. In many communities, gender influences access

Table 1 Socio-economic characteristics of households in Kirege ($n = 50$)

Characteristics	Type	Frequency	Age (%)
Gender of household head (HH)	Male	37	79
	Female	10	21
Age of HH	25–40	25	53
	41–60	14	30
	>60	8	17
Marital status of HH	Single	2	4
	Widow/er	5	11
	Married spouse present	34	72
	Married spouse absent	6	13
Education level of HH	None	1	2
	Primary	22	47
	Secondary	20	43
	Tertiary	3	6
Average family size	0–4	23	48
	5–8	24	52

to resources which are vital in farm management in general and soil fertility management in specific.

Slightly over half of the households (53%) were headed by people of 25–40 years of age as compared to 30% of 41–60 years and 17% of above 60 years. Slightly over 50% of households consisted of ≤4 people, while 48% of households had 5–8 people. The average family size for households in Kirege was found to be about four people. Considering the age of the household head and the family structure is important because it introduces the concept of the 'farm developmental cycle' (Crowley and Carter, 2000). The attitudes towards risk (investments) and innovation are highly variable according to the phase of the farm developmental cycle in which the household is (land, capital and/or labour constraints are also related to this). Young people work hard to improve their status, are receptive of new ideas and are therefore more likely to adopt new technologies for soil fertility replenishment.

Education level of the household head also influences the kind of decisions made regarding general farm management. At least 96% of the household heads had basic (primary) education, while about 50% had received at least secondary education and only 6% had tertiary education.

Results from participatory wealth ranking revealed that type of housing is an important indicator of wealth in the community. They said that rich households have permanent houses (concrete floor, stone wall and tiled roof), while medium households have semi-permanent houses with concrete floor, timber wall and iron sheet roofing and poor households have houses with earthen floor, timber and at times mud wall and iron sheet roofing. Other indicators identified by farmers were type of livestock housing, livestock ownership, intensity of use of mineral fertilizer and the households' frequency of hiring or selling labour (Table 2). Most farmers in the medium and poor resource groups use their family as the main source of farm labour and they rely on reciprocal arrangements with neighbours to provide extra hands for planting, weeding or harvesting. Hired labour is used by better-off farmers, mainly in exchange for cash or food.

Farmers' soil fertility management strategies are also shaped by the size of the farm. Owning more land allows a farmer to grow a wider range of crops and to use different niches, thereby increasing the household's food security. Poor farmers have relatively larger farms compared to rich farmers in Kirege (Table 3). Livestock are a key productive asset and a major component of the farming system. They not only influence soil fertility by providing manure but can also be sold to purchase fertilizer. Poor farmers with no

Table 2 Indicators of the wealth status of the farmers and the characteristics of the different groups at Kirege

Indicator of wealth status	Rich	Medium	Poor
Type of housing	Concrete floor, stone wall, tiled roofing	Concrete floor, timber wall, iron roofing	Earth floor, timber/mud wall, iron roofing
Livestock ownership	Own more than two cattle	Own one cattle	No cattle but own goats/sheep and chicken
Type of livestock housing	Roofed and with concrete floor	Roofed without concrete floor	No roofing and concrete floor
Production orientation	Produce surplus for sale	Produce mainly for subsistence	Produce mainly for subsistence
Mineral fertilizer use	Use regularly and in large amount	Use regularly but in small amounts	Not regularly
Hire or sell labour	Afford to hire regularly	Do not afford to hire regularly	Sell labour locally

Table 3 Average resource endowment on the farms in the location ($n = 50$) and in selected case study farms ($n = 9$) in the different farmer resource groups in Kirege

Level	Farm type	No. of farms	No. of plots	Farm size (ha)	No. of cattle	No. of shoats	No. of chicken
Village	Rich	10	7	0.54	3	5	20
	Medium	21	5	1.08	2	3	12
	Poor	16	7	0.9	1	2	5
Case farms	Rich	3	7	0.5	2	5	18
	Medium	3	5	0.5	2	3	4
	Poor	3	7	1.2	1	3	6

cattle may not gain access to manure because they are not likely to afford to purchase; instead it is them who sell the little amounts of manure they have to the rich. Rich farmers own significantly more cattle than does any other group. Poor farmers try to raise goats, sheep and poultry and use their dung to fertilize their land.

Most households have extra earning from non-agricultural activities. Only the relatively rich farmers generate any significant income from the sale of crop and livestock produce: farmers in the resource endowment classes earn very little in this way. Most households in the area reported that the largest share of total family monetary expenses goes to meeting basic household needs, followed by expenditure on school fees, medication for family members and agricultural inputs such as fertilizers. Further discussions with farmers revealed that poorer households spent relatively more on food and other basic household needs, while richer farmers spent more on manure, fertilizer and improved seeds. This suggests that poor farmers have limited financial resources available to purchase inputs for maintaining soil fertility.

Categorizing and Describing Field Types

Different field types were identified within a farm, varying in enterprises/production activities, resource allocation and management practices, as revealed by the farm transects (see example in Fig. 1). Crop diversification is one of the strategies that farmers have adopted to cope with declining land sizes and changes in livelihood in many parts of sub-Saharan Africa. In a previous study in Central Highlands, Njuki and Verdeaux (2001) found that farmers were growing between six and seven crops because of reduction in land size, loss of market for old crops and opening of new markets for new crops. Crop allocation in smallholder farms of Kirege was most diversified in the home fields which had an average of eight crops compared to outfields with four crops (Table 4) in agreement with previous studies. The home fields were small fields around the homestead, with a variety of crops sharing small pieces of land or intercropped (grains and pulses are normally intercropped). High-value crops such as fruits and vegetables were allocated to most of the home fields, while low-value crops were allocated to the outfields (see example in Table 4). The home fields were normally managed by women and often the first fields to be planted and weeded, receiving kitchen wastes and the sweepings from the house. The home fields were also receiving spills of manure from animal shed or manure stored in heaps due to their proximity to these structures. In some cases, the cattle manure is collected in compost pits instead of heaped.

The mid-distance and outfields were those in which more extensive crops were grown. The diversity of crop types decreased with increasing distance from the homestead, hence outfields had the lowest diversity of crops (Table 4). In the mid-fields, an intermediate management situation was found, strongly influenced by the farm type. In wealthy farms, they were managed in a similar way to the home fields, though input use was less intense. In the mid-fields, most of the cash crops such as tea and coffee were planted. The outfields were distant and/or difficult to access, and the crop produce was more prone to theft, particularly in areas of steep slopes. In this type of field, associated with poor-quality land, farmers planted their woodlots or crops that are known to produce under conditions of poor soil fertility, such as sweet potatoes, cassava or Napier grass. In some farms, outfields were located in the flood plain (river banks) and in such cases, farmers planted vegetables such as arrowroots and kales (Fig. 1).

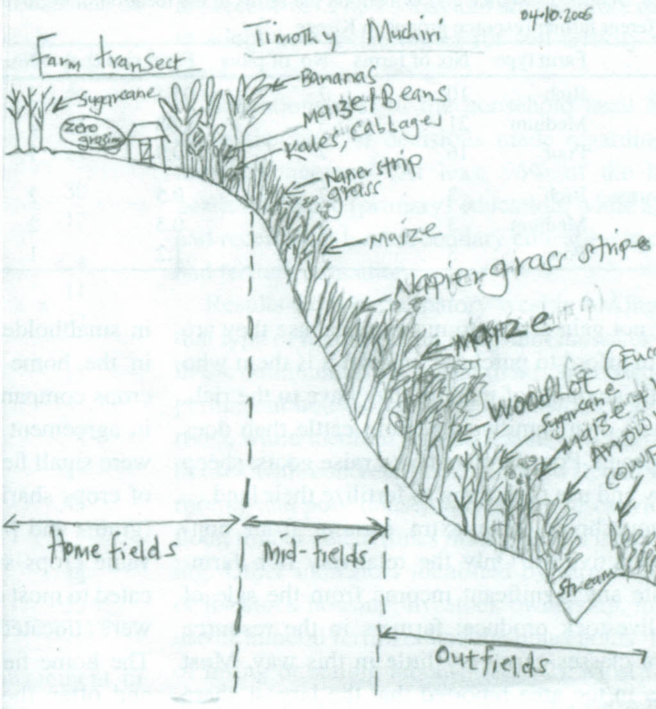

Fig. 1 Example of a farm transect drawn during farm walk in Kirege, Central Kenya (scanned from original field notes)

Variability in Resource Allocation Within Farms

As previously suggested (Brouwer et al., 1993; Carter and Murwira, 1995; Tittonel et al., 2005; Zingore et al., 2006), distance from the homestead tended to affect the allocation of production activities and resources (Tables 4, 5 and 6, Figs. 2 and 3a–d). Resource allocation in the different field types within a farm varied widely, as illustrated by the nutrient inputs calculated from the results of the resource flow mapping (Table 5). The use of organic resources varied clearly for different field types and was strongly influenced by distance from the homestead. Variations in resource allocation were also observed with regard to farmers' level of resource endowment. The wealthy farmers used large amounts of organic resources, which provided an average of 70 kg N ha^{-1}, 25 kg P ha^{-1} and 85 kg N ha^{-1} compared to the poor who used about 25 kg N ha^{-1}, 14 kg P ha^{-1} and 50 kg K ha^{-1}.

Vegetable crops grown in the home fields received most of the organic resources, followed by the cash and grain crops grown in the mid-distance fields. Very little organic resources were applied to the outfields, due to the extra effort required to transport coarse materials to distant parts of the farm (Table 5). Crop residues were used as fodder, composted to make manure or incorporated in situ. Residues used as fodder were transported to the homestead and fed to animals restricted in stalls. In some instances, crop residues were taken from the field to a compost pile or compost pit, mixed with animal manure, ashes and kitchen wastes and used as organic fertilizers in planting holes, while in others, a small proportion of the residues were incorporated into the soil directly.

Mineral fertilizers were used with varying intensities in the different field types (Table 5). The wealthy farmers applied them in all field types, and relatively high rates (34 kg N ha^{-1} and 23 kg P ha^{-1}) were used in the outfields compared to poor farmers where no fertilizer was reportedly used in the outfields (Table 5) because the resources were not enough to be used in all the fields. With regard to farm type, there was a large gap in amounts of mineral fertilizers used by the wealthiest farmers (>21 kg N ha^{-1} and 14 kg P ha^{-1}) and the poorest farmers (<5 kg N

Table 4 Average area, distance from the homestead and most frequently grown crops for the different field types, averaged over all farm types at Kirege ($n = 9$ farms)

	Home fields ($n = 35$)	Mid-distance fields ($n = 15$)	Outfields ($n = 12$)
Average area (ha)	0.07	0.18	0.23
Average distance[a] (m)	25	84	158
Minimum (m)	5	45	85
Maximum (m)	40	80	180
Most frequently grown crops (frequency %)[b]			
Maize/beans	35	83	0
Maize	25	7	18
Beans	12	0	7
Bananas	19	0	0
Coffee	2	20	0
Tea	0	7	0
Vegetables[c]	23	13	6
Potatoes	18	9	0
Napier grass	9	13	41

[a]Distance from the homestead
[b]Only one season data used
[c]Include kales, cabbages, tomatoes and onions

Table 5 Allocation of organic resources and mineral fertilizer to different field types by different resource endowment groups at Kirege

		Organic nutrient inputs (kg ha^{-1})			Mineral nutrient inputs (kg ha^{-1})		
Resource group	Field type	N	P	K	N	P	K
Rich	Home fields	75	61.3	379	12.5	7	0
	Mid-fields	60	40.7	298	23	11.6	0
	Outfields	19	9.1	55	34.1	23	0
	Mean/farm	70	25.8	85.7	21.4	13.9	0
	LSD	45.8	26.1	87.6	9.4	9.4	0
Medium	Home fields	73	42.7	145	28.6	24.9	0
	Mid-fields	57	36.2	119	1.8	6.3	0
	Outfields	15.5	16.1	33	5.6	2	0
	Mean/farm	49.2	39.4	244	13.8	11.1	0
	LSD	44.3	26.1	194.7	20.3	22.1	0
Poor	Home fields	54.2	30.5	106	2.6	2.6	0
	Mid-fields	15.5	8.5	30	2.3	2.3	0
	Outfields	8.1	4.6	16	0	0	0
	Mean/farm	25.9	14.5	50.7	1.6	1.6	0
	LSD	24.5	16.1	55.9	1.6	1.6	0

ha^{-1} and 5 kg P ha^{-1}). The wealthy farmers distributed mineral fertilizers evenly across their farms but preferentially targeted organic resources (read manure) to the plots closest to the homesteads, which received about 75 kg N ha^{-1} and 61 kg P ha^{-1} from manure compared with 60 kg N ha^{-1} and 40 kg P ha^{-1} on the mid-fields and 19 kg N ha^{-1} and 9 kg P ha^{-1} on the outfields.

Total Nutrient Inputs and Partial Nutrient Balances

As observed previously with regard to allocation of organic resources and mineral fertilizers, total nutrient inputs calculated for different field and farm types indicated that most inputs (N, P and K) were applied

Table 6 Total nutrient inputs and partial balances of different field types for the three different resource endowment groups in Kirege

		Total nutrient inputs (kg ha^{-1})			Partial nutrient balances (kg ha^{-1})		
Resource group	Field type	N	P	K	N	P	K
Rich	Home fields	109.1	72.9	379	41	46.8	29
	Mid-fields	72.5	47.7	298	8	33.8	−20
	Outfields	42	32.1	55	2	21.2	−15
	Mean/farm	74.5	50.9	244	17	67.8	−2
	LSD	38.6	23.6	194.6	24.2	14.4	30.6
Medium	Home fields	101.6	67.3	145	16.1	39	47
	Mid-fields	58.8	42.5	119	2.1	34	4
	Outfields	21.1	18.1	33	−43.2	11	−84
	Mean/farm	60.5	42.6	99	−8.3	28	−11
	LSD	46.6	28.4	67.6	35.6	19.2	77
Poor	Home fields	56.8	32.8	106	−29	27.9	−57
	Mid-fields	17.3	11.1	30	−77	6	−171
	Outfields	8.1	4.6	16	−169	2.6	−188
	Mean/farm	27.4	16.2	50.7	−91.7	12.2	−138.7
	LSD	29.8	16	55.8	81.2	14.8	28.2

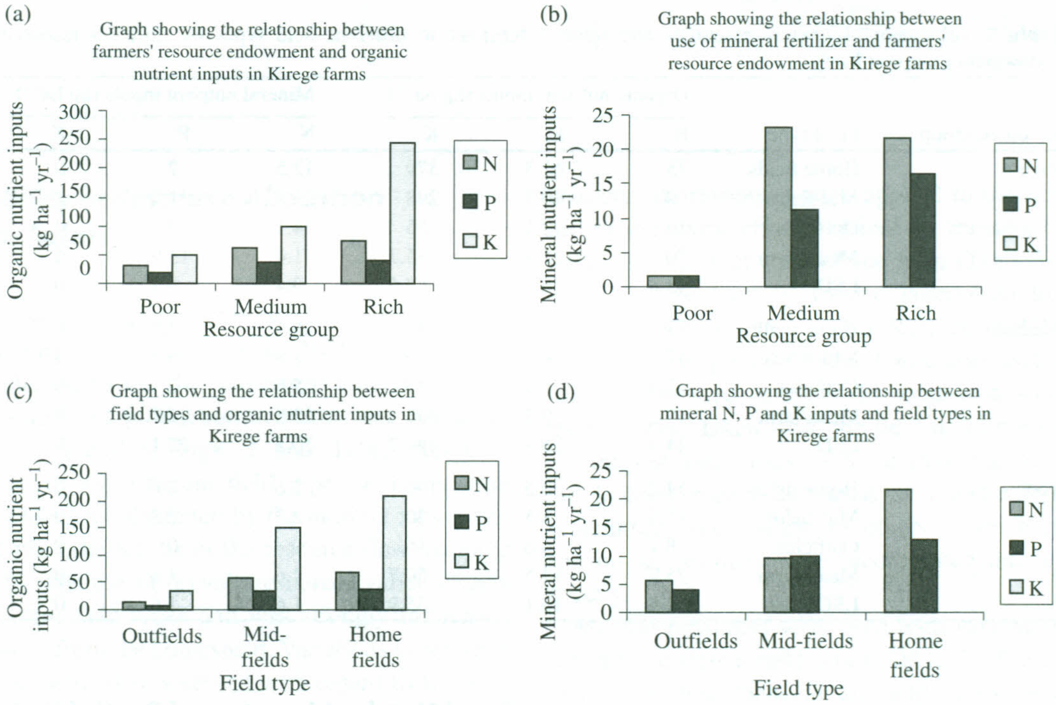

Fig. 2(a–d) Allocation of organic resources and mineral fertilizer to different fields and farm types in Kirege, Central Kenya

to the home fields. Although the average rates of nutrient inputs at farm level for wealthy and medium groups were close to the recommended (60 kg N ha^{-1} and 60 kg P ha^{-1}), calculations at field level revealed that little nutrients were applied to the outfields and especially in the medium and poor farms (Table 6). Total N and P inputs differed little in the home fields of rich and medium farms, i.e. 101 kg N ha^{-1}, 72 kg P ha^{-1} and 101 kg N ha^{-1}, 67 kg P ha^{-1} respectively. On average, large amounts of K (>50 kg ha^{-1}) were

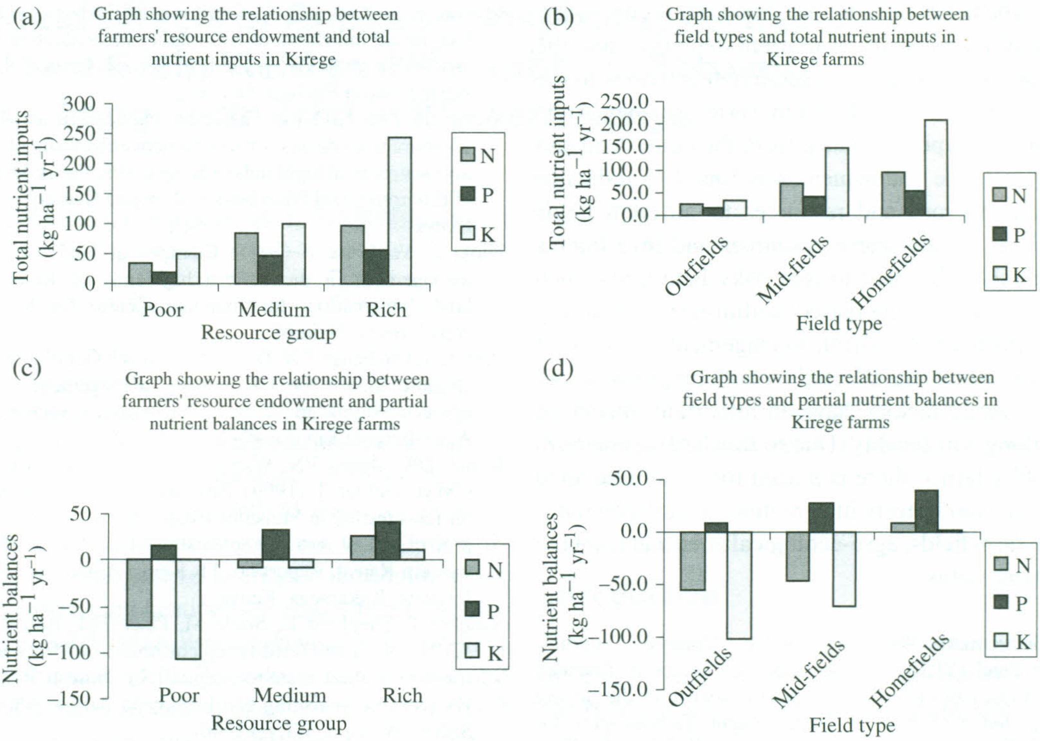

Fig. 3(a–d) Total nutrients inputs and partial balances for the different fields of the case study farm types (rich, medium and poor) at Kirege, Central Kenya

applied to all farm types and all this was obtained from organic resources as no K was available from mineral fertilizers because farmers used nitrogen- and phosphorus-based fertilizers whose potassium content, if any, is negligible.

Partial nutrient balances at field scale revealed the existence of N 'accumulation' areas within the wealthy farms and home fields of medium farms. N, P and K partial balances were largest on the wealthy farms, averaging 17 kg N ha^{-1}, 67 kg P ha^{-1} and –2 kg K ha^{-1}. The partial balances on the wealthy farms were largest on the home fields (41 kg N ha^{-1}, 46 kg P ha^{-1} and 29 kg K ha^{-1}) but decreased (8 kg N ha^{-1}, 33 kg P ha^{-1} and –20 kg K ha^{-1}) in the mid-fields and (2 kg N ha^{-1}, 21 kg P ha^{-1} and –15 kg K ha^{-1}) in the outfields. The partial N balances were negative for outfields in medium farms and all fields of the poor farms, illustrating that the amount of N added from both organic and mineral fertilizers was obviously less than the amount of N harvested with the biomass removed (Fig. 3a–d). P balances were found to be positive in all the farms and field types, although in some fields, the situation was almost in equilibrium (see Table 6, Fig. 3c and d).

In agreement with earlier observations (Mapfumo and Giller, 2001), the areas being depleted were much larger than the areas of 'accumulation', leading to an overall negative nutrient balance at farm scale for medium and poor farms. Household wastes and crop residues from other fields were brought to the home fields in the form of compost. Besides, nutrients accumulated in the home fields would not be efficiently used by grain and pulse crops often sparsely planted and shaded by banana plants and trees, affecting the magnitude of nutrient outflows as harvested crop parts. Typically, most inputs (e.g. fertilizers, manure, improved seeds) were applied in the home fields and farmers reported that their productivity was very high (80–90%).

Conclusions

The participatory monitoring approach adopted in this work helped to increase the understanding of the management aspects of smallholder farms that affect soil fertility. The heterogeneity in agricultural productivity, in terms of the intensity of nutrient depletion, and the allocation of resources and production activities to the different fields within the farm varied in magnitude between farm types. Distance from the homestead and level of resource endowment was found to influence allocation of crops and resources to different fields in the farms. Since scarce resources and investments are preferably allocated to less risky land units, such a pattern results in increased within-farm variability in soil fertility management. Management decisions at farm scale, which are affected by both biophysical and socio-economic factors, have an important impact on the resulting soil fertility. Due to this heterogeneity in smallholder farms, there is a need for a more targeted approach to soil fertility intervention that differentiates between farm fields, agro-ecological zone and resource endowment status.

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